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Accumulation of jitter in cascaded wavelength converters based on semiconductor optical amplifiers

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Introduction

Wavelength converters will be employed in future WDM networks to, e.g., reduce the wavelength blocking. The converters can, however, cause timing jitter that will accumulate in the network and thereby set an upper limit to the network size. Therefore, the accumulation of jitter through cascaded converters is important and is investigated here.

Focus is on the cascability of converters based on cross-gain modulation (XGM) but the results are applicable to interferometric wavelength converters as both techniques are based on modulation of carriers in semiconductor optical amplifiers (SOAs) [1]. So far shortening of the SOA length has been identified as a way to minimize the jitter accumulation. This is, however, at the expense of a lower modulation bandwidth. We show that the jitter accumulation in a long SOA (1500 μm) can be minimized by adjustment of the optical power levels. This enables all-optical wavelength converters to be cascaded at high bit rates.

Network requirement

Wavelength converters could be placed (i) at network interfaces for adaption between two different wavelength grids or (ii) in switch blocks enabling switching in the wavelength domain [2]. In both cases situations will occur, where the components must convert to the same wavelength. This can be accomplished by counter-propagating the signal and the CW light in an XGM converter as sketched in Fig. 1. However, this scheme constitutes a worst case for the jitter accumulation. In the following methods for minimizing the jitter accumulation are given.

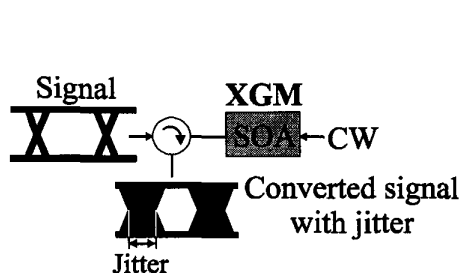


Fig. 1: Jitter arising from counter-propagation in an XGM converter.

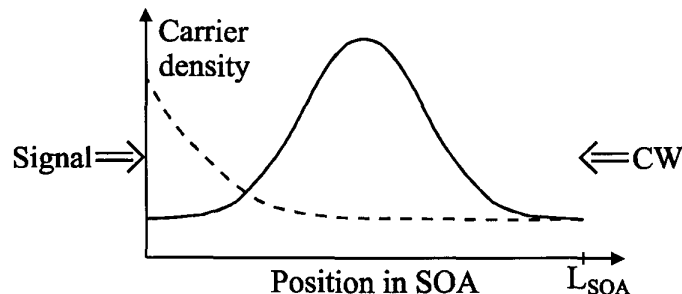


Fig. 2: Carrier density distributions in the XGM-SOA for a fixed CW power with an equal (—) and a higher (- -) signal power level.

Jitter

The jitter generated in the SOA based XGM converter is caused by the power dependent distribution of the carriers in the SOA. Fig. 2 shows two carrier distributions versus the position in the SOA, when the signal is introduced from the left and the CW light from the right. The solid curve is obtained when the signal and the CW power levels are equal causing a symmetric carrier distribution. The dashed curve shows the carrier density when the signal power is significantly higher than the CW power. In this case, the signal determines the carrier distribution because more carriers are depleted as the signal is amplified. Since the intensity of the incoming signal is modulated the carriers will redistribute for marks and spaces as shown in Fig. 2.

Due to the propagation time this movement of the gain in the longitudinal position of the SOA corresponds to a movement in time for the converted signal depending on the bit pattern. The result is that the converted signal will fluctuate resulting in an eye closure as shown in Fig. 1.

Results

The jitter accumulation is investigated with a model similar to the one described in [1]. Conversion to the same wavelength (1555 nm) of a pseudo random bit sequence is carried out in the XGM converter. After each cascaded component the power level of the converted signal is adjusted to maintain a fixed mean signal power level. A 1500 μm long SOA biased with a current density of $\sim 25 \text{ kA/cm}^2$ is examined. The initial extinction ratio of the 10 Gbit/s pulse train is 13 dB.

In fig. 3 the extinction ratio versus the number of cascaded converters is shown for four different signal powers with a constant CW power of -6 dBm. As seen the extinction ratio decreases for every conversion as expected for XGM conversion to the same wavelength [1]. It is also observed that the extinction ratio decreases the most for low signal powers, which is due to a weaker gain modulation. The extinction ratio for a high signal power of 6 dBm remains very high (>12 dB) until the 18th converter after which the extinction ratio becomes unstable. The high extinction ratio together with the high signal power level causes a strong longitudinal movement of the SOA gain. The result is a severe eye closure due to jitter accumulation making it difficult to determine the extinction ratio.

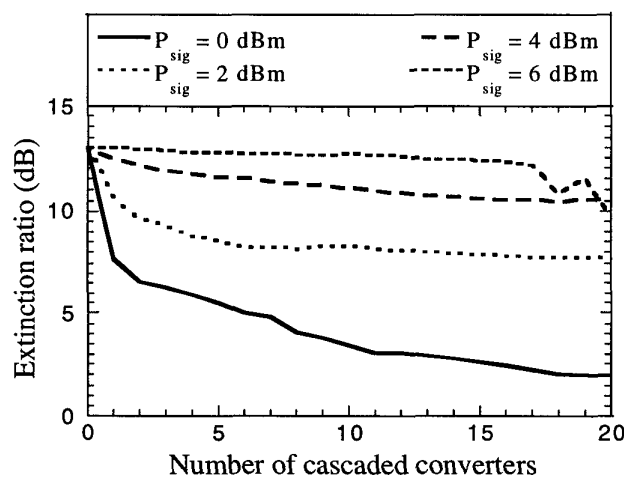


Fig. 3: The extinction ratio as a function of the number of cascaded converters. The CW power is -6 dBm while the signal power is a parameter.

Clearly, a trade-off between a high extinction ratio and a small amount of accumulated jitter exists. In the following the jitter accumulation will be investigated thoroughly.

As the movement in the carrier distribution is determined by the ratio between the signal power and the CW power, Fig. 4 shows the jitter found after 10 and 20 converters as a function of this ratio. Curves for different CW power levels are shown all having a minimum at 9-10 dB. As seen, power optimization makes it possible after 20 converters to obtain as little as ~20 ps jitter corresponding to a fifth of the time slot. The extinction ratio for all of the values near the jitter minimum is higher than 9 dB after 20 converters. As an example, a signal power of 5 dBm and a CW power of -4 dBm yields an extinction ratio of 9.6 dB and an accumulated jitter of only 17 ps after 20 converters. Finally, it is noted that any drift in the signal power level can be counteracted by control of the CW power ensuring a small amount of jitter and a high extinction ratio.

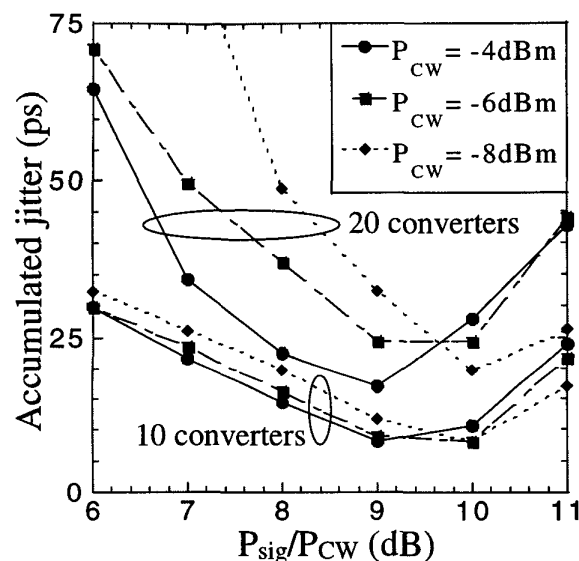


Fig. 4: The accumulated jitter for different CW power levels as a function of the ratio between the signal and CW power. Curves are shown both after 10 and 20 converters. The bit rate is 10 Gbit/s corresponding to a time slot of 100 ps.

Conclusion

The jitter accumulation for conversion to the same wavelength using the counter-propagating XGM scheme was investigated. A trade-off between a high extinction ratio and a small amount of accumulated jitter was found predicting that the ratio between the CW and mean signal power levels should be 9-10 dB. A cascade of 20 converters all converting to the same wavelength is predicted feasible with an extinction ratio of 9.6 dB and an accumulated jitter of only 17 ps. As the results found here are applicable to interferometric converters, we predict that large-scale high speed all-optical networks can employ wavelength converters without being limited by jitter accumulation from the converters.

References

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- [2] M.W. Chbat et al., Proc. of ECOC'96, Paper WeP.11, pp. 3.253-3.256, Sept. 1996